Ethio Resource Group
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GTZ SUN ENERGY Project

Water Boiling Test Results

Of Various Types of Household and Institutional Wood Stoves

for Non-Injera Cooking

(Draft)

December 2009

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I. Introduction

An assessment has been conducted in early November 2009 to evaluate Tikikil and institutional rocket stove producers and consumers. Some of the feed-backs obtained from users were suggestions for a bigger version of Tikikil to accommodate larger pots. During the assessment, it was learnt that Tikikil which was initially designed for household use, is also used by commercial users such as hotels and restaurants. Seeing the intensity of work in the commercial sector, it was recommended to build another variation of Tikikil which is more robust and can accommodate pots up to 32cm diameter. Larger size Tikikil is now available in two different types of materials. For a commercial application, a more robust Tikikil (also labeled Delux Tikikil) is made with thicker mild steel (1mm thick). Another version but similar in size with Delux Tikikil is made with galvanized sheet metal of 0.6mm thickness. The one with galvanized material is primarily designed for household use. The larger size household Tikikil which is designed for households also has a smaller detachable skirt for smaller pots. Parallel with manufacturing of large size Tikikil stoves, an institutional rocket stove of 18cm by 18cm combustion chamber size with chimney was also designed. Prototypes of the above mentioned stoves were manufactured. See the pictures of the stoves below.

Delux Tikikil	Double skirt Tikikil	Open Fire	Institutional Rocket stove with chimney
			

In order to evaluate the performances of these stoves, a series of Water Boiling Tests (WBT) were conducted. The results are presented below.

II. Test methodology

The Shell Foundation Household Energy Project WBT version 3 test protocol was used to evaluate the performances of larger size Tikikil stoves. A pot size of 32 cm diameter and ten litres of water was used to test Delux Tikikil. The double skirt stove was tested with the smaller skirt and a 24 cm diameter pot with five litres of water was used in this stove. Three tests were conducted on each of these stoves. The results of both were compared with an Open Fire.

On the institutional rocket stove four tests were conducted. In the first test, high power tests, for cold and hot starts, and simmering were separately conducted using the Shell Foundation test protocol. The main purpose of conducting this test was to compare the results with that of a chimneyless institutional rocket stove previously tested. To keep all parameters similar, the test was conducted with 75 litres of water.

The Shell Foundation test protocol is not convenient to apply for testing institutional stoves with very large volume of water. Measuring such large amount of water in a very limited time is difficult and affects the accuracy of the results. Therefore, in the following three tests, only an overall efficiency of the stove was measured. A simmering time of 45 minutes was maintained after boiling. Fuel calculation calculations were adjusted for moisture contents and remaining char embers.

To run the stoves efficiently, the amount of firewood that was fed to the stoves during the high power tests was controlled to the level where wood burning rate is just sufficient. List of instruments used to conduct the WBT includes a digital balance (30 kg maximum capacity, 1 gm precision), a thermocouple and a moisture meter.

III. Discussion of test results

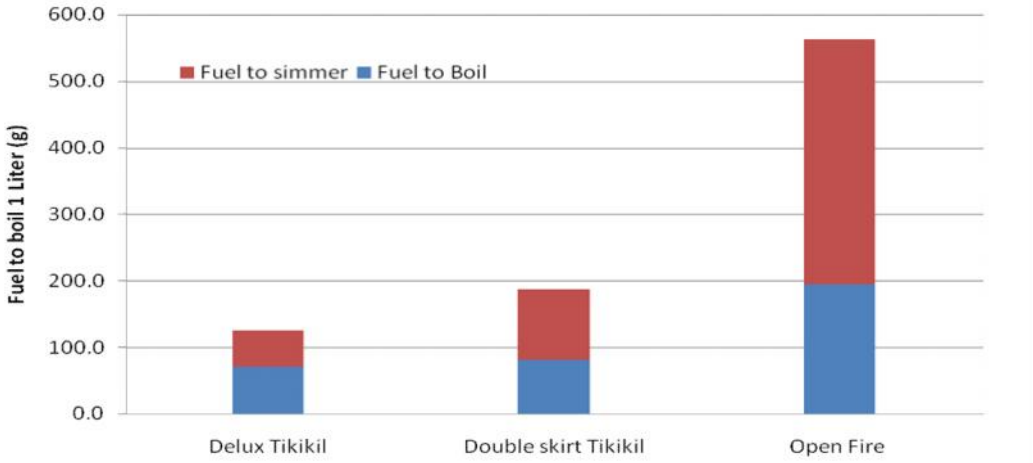
1 Results of larger Tikikil stoves

The performances of the stoves were evaluated based on their fuel consumption, thermal efficiencies, time to boil, fire power and turn-down ratio. Ultimately, the relative fuel saving of the stove against Open Fire was compared based on their fuel consumption index. Since these stoves are primarily designed for household cooking the high power cold start tests are considered to represent household situation more than the hot start tests. Hence, fuel saving comparison against Open Fire is done based on high-power/ cold-start test results.

1.1 Fuel Consumption

Fuel consumption in this regard is calculated based on the amount of temperature corrected fuel consumed by the stove to bring a litre of water to boiling. Figure 1 below shows the fuel consumption index to bring one litre of water to boiling and fuel consumption to simmer the same amount of water for 45 minutes.

Figure 1.1: Fuel consumption to boil (cold start) and simmer one litre of water



The graph in Figure 1 above shows fuel consumption in cold start high power test and simmering. As it can be seen from the graph, the fuel consumed by Delux Tikikil, Double skirt Tikikil and Open Fire were 70.73 gm, 80.93 gm and 194.44 gm respectively. In hot start high power test fuel consumptions by these stoves were 63.93 gm, 72.32 gm and 207.04 gm (see Annex 1) while for simmering the results were 55.14, 106.16 and 368.52 grams in the respective orders described above.

Since Delux Tikikil was tested with larger volume of water, the comparison of its results with that of the other stoves should only be taken as indicative. Taking the advantage of larger pot size, Delux Tikikil consumed the least amount of fuel to bring a litre of water to boiling temperature.
The fuel saving of these stoves compared to Open Fire based on results of high power cold start test is over 60% (see section 6 for details).

1.2 Thermal Efficiency

The thermal efficiencies of the stove show similar trend to the fuel consumption index discussed above. All of these stoves except Open Fire were tested with skirts. The thermal efficiencies of each stove are indicated in Table 1 below.

Table 1.1:- Thermal efficiency of the stoves

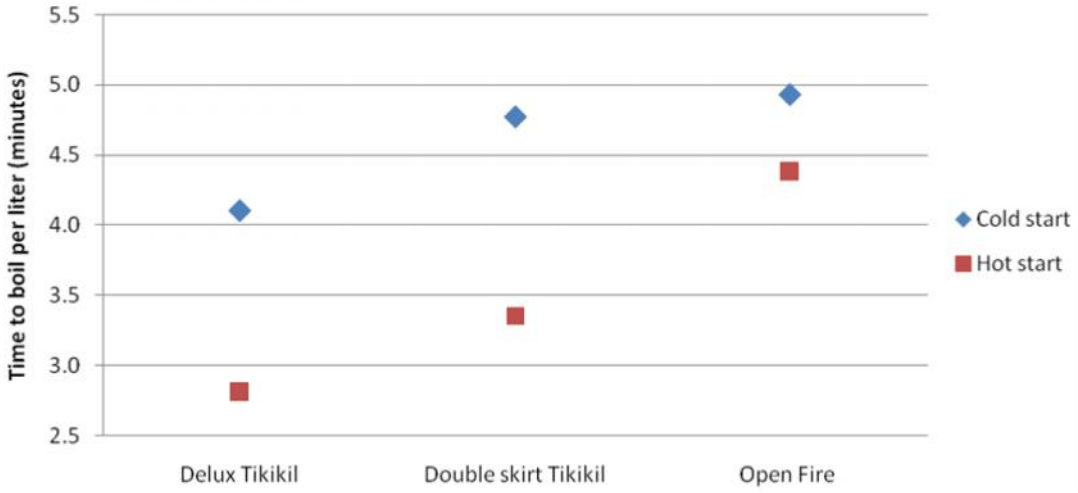
Type of Test	Type of Stoves		
	Delux Tikikil	Double skirt Tikikil	Open Fire
High Power	34%	28%	11%
Simmering	34%	28%	9%

Delux Tikikil, tested with a larger pot and 10 litres of water, showed a mean thermal efficiency of 34%. Double skirt Tikikil and Open Fire exhibited a mean thermal efficiency of 28% and 11% respectively. The thermal efficiencies for Delux Tikikil and Double skirt Tikikil is similar in both high power and simmering tests. Open Fire, however, showed a lower thermal efficiency of 9% during simmering tests.

1.3 Time to Boil

The stoves tested are also compared by the amount of time they take to raise one litre of water to boiling temperature. Temperature compensated time to boil for cold start and hot start tests is presented in Figure 2 below.

Figure 1.2: Time required to boil one litre of water



In both cold and hot start tests the average time taken to boil a litre of water was the minimum for Delux Tikikil followed by Double Skirt Tikikil and Open Fire. There is a two minutes difference between the shortest time taken by Delux Tikikil (2.8 minutes) and the longest time taken by Open

Fire (4.9 minutes) in boiling a litre of water. The boiling time for Double skirt Tikikil and Open Fire is almost similar for cold start tests. However, Double skirt Tikikil got the advantage of the hot liners to reduce the boiling time to 3.4 minutes.

1.4 Fire Power

Fire power for the high power cold start test for Delux Tikikil, Double skirt Tikikil and Open Fire are 5.1, 5.1, and 12.3kW respectively. The two stoves except Open Fire have similar fire power. Figure 3 below shows fire power for high power cold start test and simmering for the three stoves.

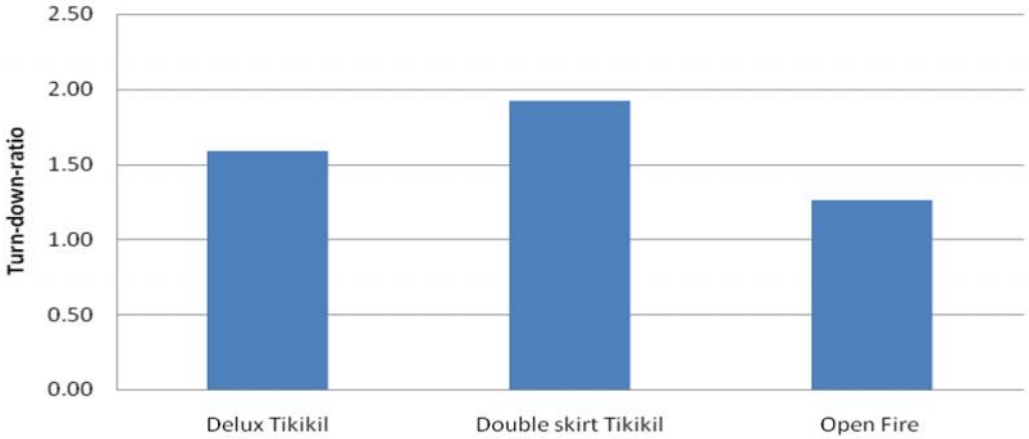
Figure 3: Firepower for various stoves

During simmering the fire power was reduced to 3.2, 2.9 and 9.7 kW for Delux Tikikil, Double skirt Tikikil and Open Fire respectively.

1.5 Turndown Ratio

Turndown ratio is also another important parameter to gauge the performance of stoves. It tells the ability of the stove to adjust to various fire powers. Figure 4 below shows the turndown ratio for the stoves tested.

Figure 4: Turn down ratio



As indicated in Figure 4 above, Double skirt Tikikil showed the highest turndown ratio followed by Delux Tikikil. Open Fire has the lowest turndown ratio of the three stoves.

1.6 Fuel Saving Compared to Open Fire

Fuel saving potential of the two improved stoves against the Open Fire stove is presented below in Table 2. The comparison is made by taking the temperature compensated fuel consumption index for each stove.

Table 1.2: Percentage of Fuel Saving of the stoves over Open Fire

Type of Test	Type of Stoves	
	Delux Tikikil	Double skirt Tikikil
High Power	67.85	60.20
Simmering	73.19	67.19
Average	70.52	63.70

As can be seen from Table 2 above, the average fuel saving by each of the two stoves is over 60%. The higher fuel saving observed in the case of Delux Tkikil is primarily due to the larger pot size and larger volume of water used for testing.

2 Results of Institutional Rocket Stove with chimney

As described in the methodology section earlier in this report, four tests were conducted on the institutional rocket stove with a chimney. One of the tests was using the Shell Foundation WBT protocol data forms and calculations but with 75 litres of water. The purpose of this test was to compare the performance of the stove with the results of previous tests on the chimneyless version. The other three WBT tests were to determine the overall efficiency of the stove. In these tests, there was no intermediate measurement of water or remaining wood. Measurements were taken in the beginning of the test and finally after completing the simmering test.

A. High power (cold and hot start) and simmering test

Comparison of performances of rocket stoves with chimney and without chimney, as shown in Table 2.1 below, does not show any significant difference. Thermal efficiencies around 40% but with slightly bigger figure in high power hot start test are exhibited.

Table 2.1: Comparison of institutional rocket stoves with and without chimney.

Test Phases	Unit	Rocket stove with chimney	Rocket stove no chimney
1. HIGH POWER TEST (COLD START)	**units**	**Average**	**Average**
Temp-corrected time to boil	min	52.2	54.5
Thermal efficiency	%	40.2	42
Firepower	watts	22941.0	20615.3
2. HIGH POWER TEST (HOT START)			
Temp-corrected time to boil	min	38.7	43.3
Thermal efficiency	%	45.6	48
Firepower	watts	27317.3	25447.9
3. LOW POWER (SIMMER)			
Thermal efficiency	%	40.0	39.1
Firepower	watts	9504.8	16632.9
Turn down ratio	--	2.4	1.2

The time required to boil and firepower are very much similar for both stoves. Based on the test results, it can be concluded that the performance of the stove with and without chimney is very much

similar. However, the additional material and workmanship for the chimney stove could increase the total cost by about 20%. Summary of the test results are presented in Table A2-2 in Annex 2.

B. Overall thermal efficiency test

In the overall thermal efficiency test, high power and simmering tests were not separately measured or calculated. Measurements were taken in the beginning and end of the tests. Three Water Boiling Tests with ninety litres of water were conducted to evaluate the overall efficiency of the institutional stove with chimney. In addition to this, to make a comparison with previous tests, an overall efficiency with 75 litres of water was calculated by combining the high power cold start and simmering phases of the test described in section 2A above. In the following section the test results of the institutional rocket chimney stove with ninety litres are indicated with asterisks.

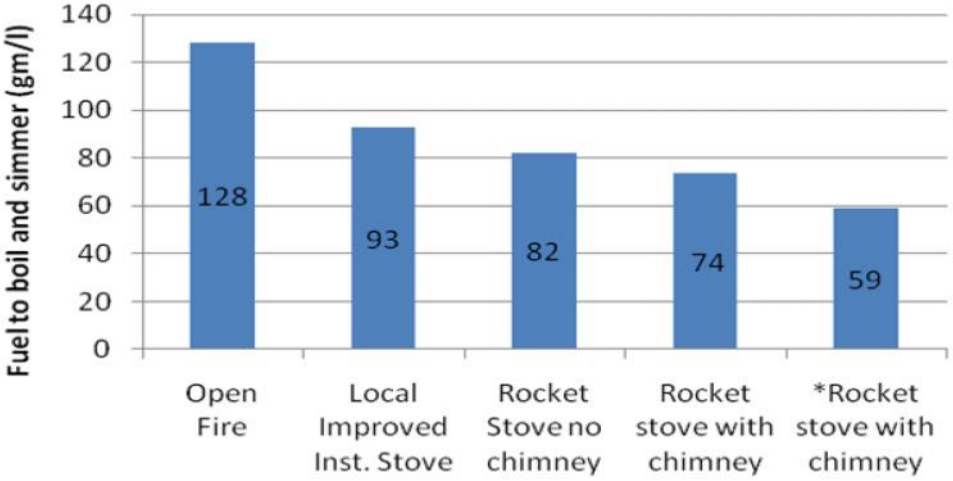
The performances of the stoves were compared by fuel consumption, overall thermal efficiency, time required to bring a litre of water to boil and fire power. The results are discussed below. The summary of the test results are shown in Table A2-1 in Annex 2.

2.1 Fuel Consumption

The fuel consumption by each stove to boil and simmer a litre of water is presented in Figure 2.1 below. Fuel consumption in this case is calculated by dividing the equivalent dry wood consumed by the amount of water remaining at the end. Since a certain mass of water is evaporated during the test, the final weight of water is reduced. The calculation for the fuel consumption doubly discredits the stoves performance as it does not account the energy consumed to evaporate the water. Hence, fuel consumption index is not an accurate parameter to compare the performance of the stoves. It should only be indicative.

In Figure 2.1, fuel consumptions by Open Fire, locally designed improved institutional stove, and rocket stoves with and without chimney are indicated. The local improved institutional stove is also a sunken-pot type but different from rocket stoves.

Figure 2.1: Fuel consumption to boil and simmer one litre of water



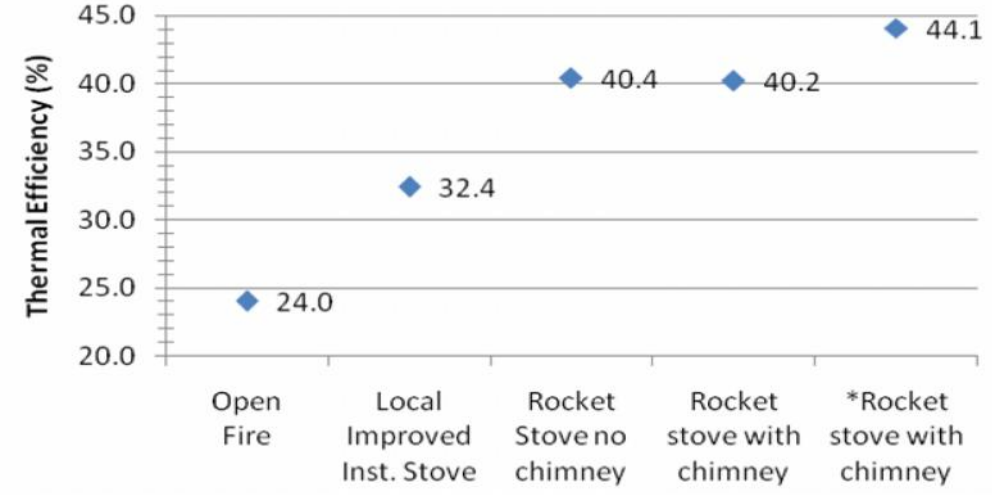
The rocket stove with chimney indicated by asterisk represents the mean result of tests with 90 litres of water. All the other stoves are tested with 75 litres of water. The stove when tested with 90 litres of water consumed less fuel per litre of water boiled and simmered (59gm/l) compared to its

performance when tested with 75 litres (74gm/l). One of the reasons for the low performance with 75 litres could be that the stove was oversized as it is designed for over 90 litres of water. Comparing the chimneyless rocket stove and the one with the chimney, with 75 litres of water, the one with chimney seems to consume less fuel per litres of water boiled and simmered. This is partly due to the unaccounted energy consumed to evaporate certain volume of water. Thermal efficiency is a rather better method for comparing performance as it accounts all energy consumed by the volume of water boiled and evaporated.

2.2 Overall Thermal Efficiency

Overall thermal efficiencies of various stoves is presented in Figure 2.2 below. The efficiency of Open Fire is 24% and is the lowest. The locally designed improved stove has an overall efficiency of 32%.

Figure 2.2: Overall thermal efficiency of the stoves



In terms of the overall thermal efficiency, the chimneyless rocket stove and the one with chimney performed similar exhibiting an overall efficiency of about 40%. When the same stove was tested with 90 litres of water a slightly higher efficiency of 44% was observed. This could be because the stove was performing at a load it is designed for.

2.3 Fuel Saving Compared to Open Fire

Fuel saving comparison by thermal efficiencies is more accurate as it accounts the energy required for boiling and evaporating water. Based on comparisons with thermal efficiencies, rocket stove shows about 68% fuel saving over open fire while the locally designed improved stove shows 35% fuels saving. See Table 2.1 below. Comparison of the rocket stove tested with 90 litres of water with Open Fire which was tested with 75 litres may not be accurate as the procedures are not similar.

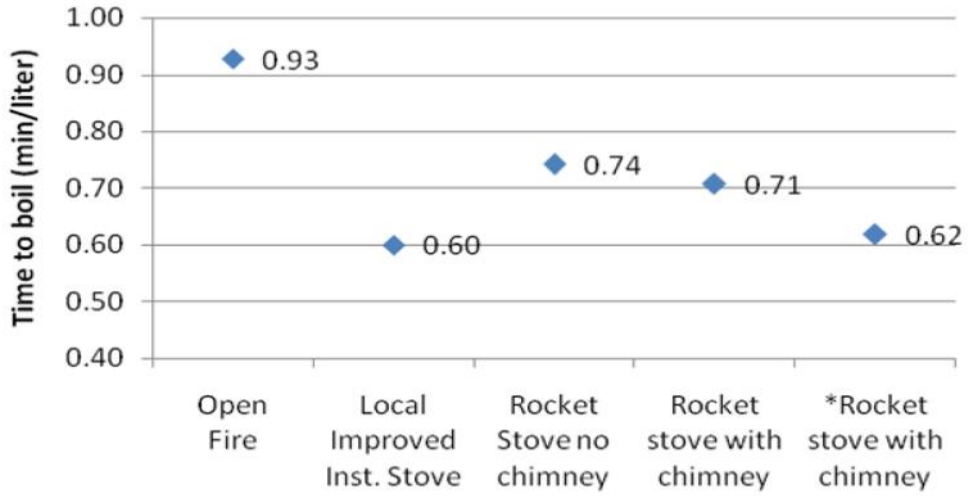
Table 2.1: Comparison of stoves with Open Fire

Fuel saving over Open Fire	Stove Type			
	Local Improved Inst. Stove	**Rocket Stove no chimney**	**Rocket stove with chimney**	***Rocket stove with chimney**
Based on specific fuel consumption	27.6%	36.2%	42.5%	54.0%
Based on thermal efficiency	34.9%	68.1%	67.3%	83.3%

2.4 Time to Boil

Figure 2.3 below shows the time taken by each stove to bring one litre of water to boiling. In should be noted that all stoves took less than one minute to bring a litre of water to boiling temperature. Open Fire taking 0.93 minutes was the longest time taken to boil. All the other stoves took almost equal time.

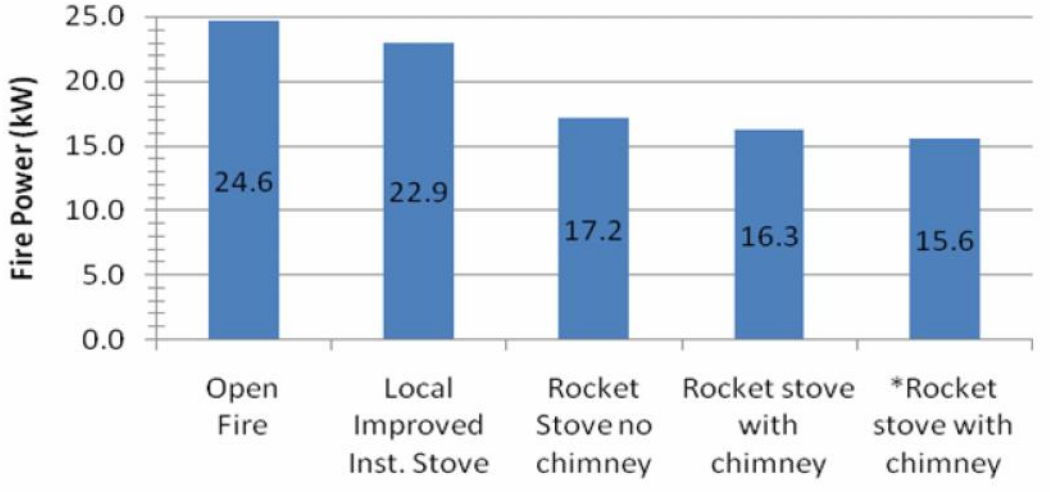
Figure 2.3: Time required to boil one litre of water



2.5 Fire Power

The overall firepower for each stove is indicated in Figure 2.4. Open Fire showed the highest fire power 24.6kW followed by the locally designed improved stove, 23kW. The rocket stoves with and without chimney showed similar firepower between 16 and 17kW.

Figure 2.4: Fire Power for different stoves



Annex 1:- Summary of all tests for Tikikil and Open Fire collected from the results Sheet of the data and calculation form.

Type of Test	**units**	**Delux Tikikil**					**Double skirt Tikikil**				
1. HIGH POWER TEST (COLD START)		**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Temperature corrected time to boil	min	43.55	40.68	38.96	41.06	2.32	30.55	21.42	19.65	23.87	5.85
Burning rate	g/min	16.41	15.88	16.76	16.35	0.44	14.42	16.36	18.72	16.50	2.15
Thermal efficiency	--	0.34	0.35	0.34	0.34	0.00	0.28	0.27	0.28	0.28	0.00
Specific fuel consumption	g/litre	73.20	64.67	66.46	68.11	4.50	92.85	69.46	71.28	77.86	13.01
Temp-corrected specific consumption	g/litre	76.25	67.65	68.29	70.73	4.79	94.10	72.86	75.83	80.93	11.50
Firepower	watts	5,151.92	4,987.00	5,261.95	5,133.62	138.38	4,527.02	5,138.01	5,876.72	5,180.58	675.86
2. HIGH POWER TEST (HOT START)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Temperature corrected time to boil	min	32	26	26	28.1	2.99	22.60	14.28	13.46	16.78	5.06
Burning rate	g/min	19	24	23	22.2	2.67	16.26	23.24	25.95	21.81	5.00
Thermal efficiency	--	0.36	0.32	0.34	0.3	0.02	0.29	0.29	0.28	0.29	0.01
Specific fuel consumption	g/litre	60	64	62	62.0	1.67	75.57	65.90	67.07	69.51	5.28
Temp-corrected specific consumption	g/litre	63	67	62	63.9	2.38	76.38	69.13	71.45	72.32	3.71
Firepower	watts	6,036	7,672	7,176	6961.3	838.94	5,104.07	7,297.31	8,147.82	6,849.73	1,570.46
3. LOW POWER (SIMMER)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Burning rate	g/min	10.76	11.04	9.26	10.4	0.96	10.90	9.71	6.81	9.14	2.10
Thermal efficiency	--	0.34	0.34	0.34	0.3	0.00	0.27	0.27	0.29	0.28	0.01
Specific fuel consumption	g/litre	59	60	47	55.1	6.74	131.48	113.75	73.24	106.16	29.85
Firepower	watts	3,380	3,466	2,908	3251.1	300.52	3,422.78	3,048.92	2,137.87	2,869.85	660.91
Turn down ratio	--	1.52	1.44	1.81	1.6	0.19	1.32	1.69	2.75	1.92	0.74

Type of Test	units	Open fire with 15.5cm height			
1. HIGH POWER TEST (COLD START)		**Test 1**	**Test 2**	**Average**	**St Dev**
Temperature corrected time to boil	min	28.92	20.37	24.64	6.05
Burning rate	g/min	33.34	45.05	39.20	8.28
Thermal efficiency	--	0.11	0.11	0.11	0.00
Specific fuel consumption	g/litre	188.70	179.89	184.29	6.23
Temp-corrected specific consumption	g/litre	200.46	188.43	194.44	8.50
Firepower	watts	10,469	14,147.2	12,308.17	2,600.8
2. HIGH POWER TEST (HOT START)	**units**	**Test 1**	**Test 2**	**Average**	**St Dev**
Temperature corrected time to boil	min	21.42	22.37	21.89	0.68
Burning rate	g/min	46.32	45.24	45.78	0.76
Thermal efficiency	--	0.11	0.10	0.10	0.00
Specific fuel consumption	g/litre	195.79	199.51	197.65	2.63
Temp-corrected specific consumption	g/litre	205.38	208.69	207.04	2.34
Firepower	watts	14,544	14,205.2	14,374.76	239.76
3. LOW POWER (SIMMER)	**units**	**Test 1**	**Test 2**	**Average**	**St Dev**
Burning rate	g/min	27.78	34.18	30.98	4.52
Thermal efficiency	--	0.10	0.08	0.09	0.02
Specific fuel consumption	g/litre	338.75	398.30	368.52	42.11
Firepower	watts	8,723.9	10,731.9	9,727.94	1,419.9
Turn down ratio	--	1.20	1.32	1.26	0.08

Annex 2: - Summary of tests results of institutional rocket stoves and Open Fire

Table A2-1: Summary of test results from overall thermal efficiency tests

Parameters	Unit	Stove Type				
		Open Fire	**Local Improved Institutional Stove**	**Rocket Stove no chimney**	**Rocket stove with chimney**	***Rocket stove with chimney**
Time to boil per litre	min/l	0.93	0.60	0.74	0.71	0.62
Burning rate	g/min	78	72	54	51	49
Specific fuel consumption	g/l	128	93	82	74	59
Thermal Efficiency	%	24.0	32.4	40.4	40.2	44.1
Firepower	kW	24.6	22.9	17.2	16.3	15.6

* This test is done with 90 litres of water and hence a slightly higher efficiency. Others tests are with 75 litres of water.

Table A2-2: Summary of test results for high power and simmering tests

Test Phases	Unit	Rocket stove with chimney	Rocket stove no chimney
1. HIGH POWER TEST (COLD START)	**units**	**Average**	**Average**
Time to boil Pot	min	51.5	54.1
Temp-corrected time to boil	min	52.2	54.5
Burning rate	g/min	73.1	65.7
Thermal efficiency	%	40.2	42
Specific fuel consumption	g/litre	51.8	48.7
Temp-corrected specific consumption	g/litre	52.4	49.2
Firepower	watts	22941.0	20615.3
2. HIGH POWER TEST (HOT START)			
Time to boil Pot	min	36.9	41.2
Temp-corrected time to boil	min	38.7	43.3
Burning rate	g/min	87.0	81.0
Thermal efficiency	%	45.6	48
Specific fuel consumption	g/litre	44.2	46.2
Temp-corrected specific consumption	g/litre	46.3	48.5
Firepower	watts	27317.3	25447.9
3. LOW POWER (SIMMER)			
Burning rate	g/min	30.3	53.0
Thermal efficiency	%	40.0	39.1
Specific fuel consumption	g/litre	19.4	29.5
Firepower	watts	9504.8	16632.9
Turn down ratio	--	2.4	1.2